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## RESEARCH MEMORANDUM

THERMAL-SHOCK RESISTANCE OF A CERAMIC COMPRISING  
60 PERCENT BORON CARBIDE AND 40 PERCENT  
TITANIUM DIBORIDE

By C. M. Yeomans and C. A. Hoffman

Lewis Flight Propulsion Laboratory  
Cleveland, Ohio

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RESEARCH MEMORANDUM

THERMAL-SHOCK RESISTANCE OF A CERAMIC COMPRISING 60 PERCENT

BORON CARBIDE AND 40 PERCENT TITANIUM DIBORIDE

By C. M. Yeomans and C. A. Hoffman

SUMMARY

An investigation was conducted to evaluate the thermal-shock resistance of a ceramic comprising 60 percent (by volume) boron carbide and 40 percent (by volume) titanium diboride. Two types of quench apparatus were employed, one for drastically quenching the periphery of small disks, the other for simulating altitude blow-out conditions in a turbojet engine.

On the basis of these evaluations, the ceramic compared favorably with National Bureau of Standards body 4811C and with zirconia, but was inferior to beryllia, alumina, and titanium-carbide ceramals.

INTRODUCTION

A ceramic prepared from 40 percent by volume titanium diboride  $TiB_2$  and 60 percent by volume boron carbide  $B_4C$  and known as titanium-carbon mixed borides has been proposed for possible gas-turbine application. Preliminary to its further consideration, it is necessary to determine, among other things, its thermal-shock resistance. Thermal-shock resistance is necessary for such applications in order to withstand the heat shock encountered in starting, particularly in "hot starts," and in "altitude blow-out."

The objective of this investigation was to determine the thermal-shock resistance of a ceramic comprising 40 percent (by volume)  $TiB_2$  and 60 percent (by volume)  $B_4C$ . Two types of thermal-shock test were employed.

In one type of test, the rim of a disk was drastically quenched. The geometry of the specimen and the method of test were designed so as to permit mathematical treatment of the stress state produced by the thermal shock. However, the mathematical analysis has not been completed as yet.

The second type of test is one in which air passes at a very high velocity across a specimen and simulates the altitude blow-out conditions encountered in jet engines.

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The material used in this study was supplied by the Norton Company.

## APPARATUS AND PROCEDURE

### Preparation of Specimens

The specimens (2 in. diam. disks 1/4 in. thick) were received with rough surfaces and were therefore ground. The surface irregularities of some specimens were so deep that they could not be removed without reducing specimen dimensions excessively, while other specimens chipped during the grinding operation. The specimens were radiographed before testing.

Thermal-shock evaluation under rim-quench conditions. - The apparatus used in the rim-quench tests consists of a vertical electric resistance muffle-tube furnace from which specimens can be lowered into a quenching medium, which may be either water or air. For the water quench, the specimen is lowered from the furnace into a tank of water of known temperature. For the air quench, the specimen is lowered into an annulus which has been drilled so that it directs air jets around the periphery of the specimen.

For the purpose of the test, it is necessary that the disk lose heat only from its rim when being quenched. In order to ensure this condition the disk is sandwiched between two cylinders of low-conductivity alloy. Asbestos washers are placed between the test specimen and the alloy cylinders. These cylinders are of the same diameter as the test disk, but are approximately ten times as thick. These cylinders also help to position the disk during heating and quenching. The entire assembly, test disk, washers, and cylinders, is subjected to heating and quenching as a unit.

In order to perform a test in the rim-quenching apparatus, a furnace temperature is selected to give a quench of less severity than is believed necessary to cause specimen failure. The specimen assembly is placed in the vertical-tube furnace, which has previously been brought to the selected temperature. As soon as temperature equilibrium is indicated by a thermocouple in contact with the specimen, the specimen assembly is quenched by quickly lowering it into either the water tank or the air jets. When the specimen is cool, it is examined for cracks by a penetrant-oil method. If no crack is found, the quench is repeated from a higher (by 50° F) temperature. This procedure is continued until specimen failure is indicated by cracks or fracture.

Another specimen is then tested by the same procedure except that the initial quench is somewhat more severe and the successive quench increments are made smaller.

This process is continued with additional disks to narrow the difference between the  $\Delta T$  that does not cause specimen failure, and the  $\Delta T$  that does cause specimen failure, and to obtain a measure of the reproducibility for the material.

The largest temperature difference (furnace temperature minus water temperature) that will not fail the disk is called the survival  $\Delta T$ , and the smallest temperature difference that will fail the disk is called the failure  $\Delta T$ .

Thermal-shock evaluation under simulated altitude-blow-out conditions. - The apparatus used consisted of a furnace in which individual specimens were heated to a predetermined temperature and an adjacent air duct into which they were quickly placed after withdrawal from the furnace. The test sequence required a specimen to be quenched 25 times in succession from each of 4 temperatures, 1800°, 2000°, 2200°, and 2400° F for a total of 100 cycles or until failure, whichever occurred first. An air flow of 50 pounds per minute (265 ft/sec) at 70° to 80° F was used. A complete description of this apparatus is given in reference 1. Three specimens were evaluated in this apparatus.

## RESULTS AND DISCUSSION

The results of the rim-quenching evaluations are given individually in table I and are summarized in table II. A typical failure produced by this type of evaluation is shown in figure 1. The most severe air quench that could be obtained in this evaluation did not produce specimen failure; hence, the water quench was used subsequently to obtain specimen failure. The results of the simulated altitude-blow-out evaluation is given in table III, and typical failures are shown in figure 2.

For comparison purposes, several additional materials, which have been tested at the NACA Lewis laboratory under rim-quench conditions, are also included in table II. The titanium carbide ceramal shown on the table is believed (ref. 2) to have sufficient thermal-shock resistance for turbine-blade application. It can be seen in reference 3 that the National Bureau of Standards body 4811C is probably inadequate in thermal-shock properties for turbine-blade application.

The results of the simulated blow-out test may be compared with other materials evaluated in the same apparatus. It is reported in reference 2 that a titanium carbide ceramal containing 20 percent by weight nickel and a titanium carbide ceramal containing 20 percent by

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weight cobalt survived 25 quenches from 1800°, 25 from 2000°, 25 from 2200°, and 25 from 2400° F without failure for a total of 100 cycles and at an air flow of 265 feet per second. In this reference, it is also reported that 80 percent by weight titanium carbide plus 20 percent by weight cobalt survived a total of 100 quench cycles without failure, but at an increased air flow of 495 feet per second. In reference 1, it is reported that zircon ( $ZrSiO_4$ ) survived one quench cycle from 1800° F. A comparison of the data from both tests indicates that the composition under study has thermal-shock resistance similar to that of zircon and NBS 4811C but inferior to that of beryllia, alumina, and titanium-carbide ceramals. The titanium-carbon mixed borides probably do not have the thermal-shock resistance required for turbine blades.

#### SUMMARY OF RESULTS

1. Four specimens were given severe rim quenches; they survived quench differentials ( $\Delta T$ ) of 415°, 425°, 435° and 445° F, but failed at quench differentials ( $\Delta T$ ) of 465°, 445°, 455° and 455° F, respectively.

2. Two of three specimens tested in a simulated altitude-blow-out evaluation survived two quench cycles from 1800° F; the third survived four quench cycles from 1800° F.

Lewis Flight Propulsion Laboratory  
National Advisory Committee for Aeronautics  
Cleveland, Ohio

#### REFERENCES

1. Hoffman, Charles A., Ault, G. Mervin, and Gangler, James J.: Initial Investigation of Carbide-Type Ceramal of 80-Percent Titanium Carbide Plus 20-Percent Cobalt for Use as a Gas-Turbine-Blade Material. NACA TN 1836, 1949.
2. Hoffman, C. A., and Cooper A. L.: Investigation of Titanium Carbide Base Ceramals Containing Either Nickel or Cobalt for Use as Gas-Turbine Blades. NACA RM E52H05, 1952.
3. Freche, John C., and Sheflin, Bob W.: Investigation of a Gas Turbine with National Bureau of Standards Body 4811 Ceramic Rotor Blades. NACA RM E8G20, 1948.

TABLE I. - RESULTS OF RIM-QUENCH THERMAL-SHOCK TESTS  
ON TITANIUM-CARBON MIXED BORIDES

[Water quench.]



| Specimen       | Temperature differential survived, $\Delta T$ ,<br>°F |     |     |     |                  |     |                  |                  |
|----------------|---|-----|-----|-----|------------------|-----|------------------|------------------|
|                | Quench  |     |     |     |                  |     |                  |                  |
|                | 1   | 2   | 3   | 4   | 5                | 6   | 7                | 8                |
| <sup>a</sup> 2 | 220   | 275 | 300 | 340 | 365              | 390 | 415              | <sup>b</sup> 465 |
| 3              | 225   | 300 | 350 | 375 | 400              | 425 | <sup>b</sup> 445 |                  |
| 7              | 325   | 385 | 410 | 435 | <sup>b</sup> 455 |     |                  |                  |
| 1              | 225   | 300 | 350 | 375 | 400              | 425 | 445              | <sup>b</sup> 455 |

<sup>a</sup>Specimen subjected to rim air-quench test before water-quench test. Survived 13 quenches to 70° F increasing in severity from a  $\Delta T$  of 430° to 1600° F.

<sup>b</sup>Specimen failed.

TABLE II. - SUMMARY OF RESULTS OF TITANIUM-CARBON MIXED  
BORIDES AND TITANIUM DIBORIDE IN RIM-QUENCH THERMAL-SHOCK TEST

| Material   | $\Delta T, ^\circ F$ |        |
|--|----------------------|--------|
|  | Survived             | Failed |
| 40 percent $TiB_2$ + 60 percent $B_4C$ (by volume)     | 415                  | 465    |
| <sup>a</sup> Specimen 2                                | 415                  | 465    |
| Specimen 3   | 425                  | 445    |
| Specimen 7   | 435                  | 455    |
| Specimen 1   | 445                  | 455    |
| NBS 4811C  | 490                  | 510    |
| 80 percent by weight $TiC$ + 20 percent by weight $Co$ | 1600                 | 1700   |
| $BeO$  | 775                  | 800    |
| $Al_2O_3$  | 925                  | 950    |

<sup>a</sup> Specimen survived  $\Delta T$  of  $1600^\circ F$  in air rim-quench test.

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TABLE III. - RESULTS OF TITANIUM-CARBON MIXED BORIDES IN  
SIMULATED ALTITUDE BLOW-OUT TEST

[50 lb/min quench air at 70 to  $80^\circ F$ ; 265 ft/sec air velocity.]

| Specimen | Furnace temperature,<br>$^\circ F$ | Number of quench<br>cycles survived |
|----------|------------------------------------|-------------------------------------|
| 4        | 1800                               | 2                                   |
| 5        | 1800                               | 4                                   |
| 6        | 1800                               | 2                                   |



Figure 1. - Typical failure produced by water-quenching of periphery of ceramic disk.

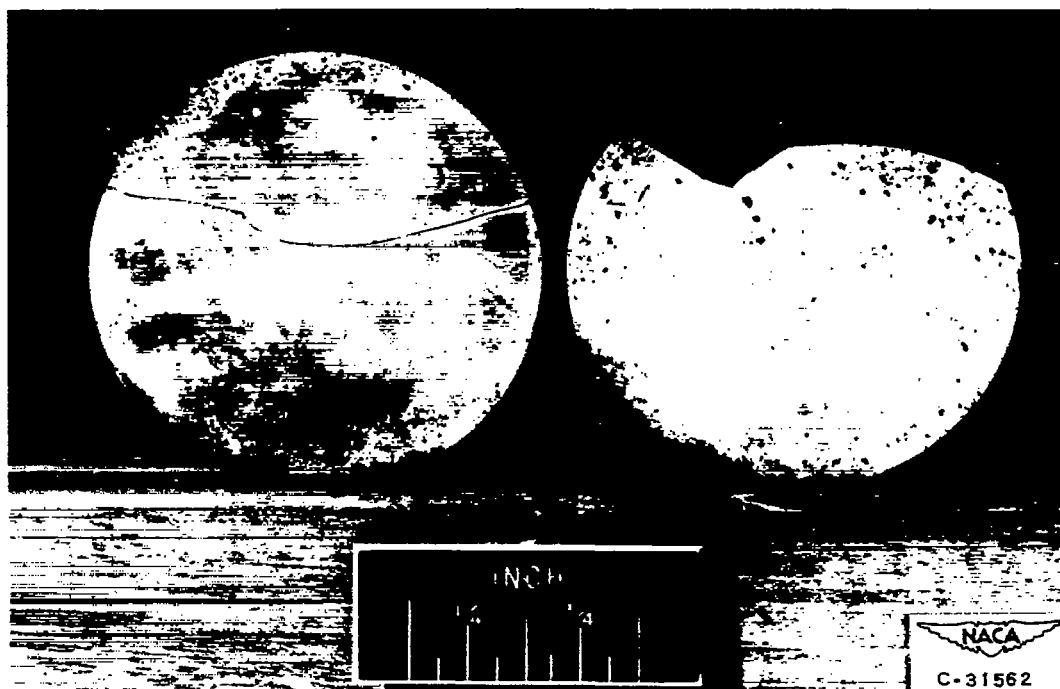


Figure 2. - Typical thermal-shock failures of ceramic disks under simulated altitude blow-out conditions.

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